

# Chemical fit at RHIC

Masashi Kaneta



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*V.Koch, H.G.Ritter, N.Xu (LBNL),*

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*and Organizers*

# Outlook

- Introduction
- Model
- Data
- Freeze-out parameters
- Model uncertainties
- Summary
- Open issues



# Introduction

- Bulk properties of the heavy ion collisions
- Statistical approach for particle production
- Dynamical information – may be lost?
- Chemical freeze-out
  - occurs at an uniform condition?  $\langle E \rangle / \langle N \rangle \sim 1 \text{ GeV}$
  - SIS ( $<1 \text{ GeV}$ ), AGS ( $\sim 5 \text{ GeV}$ ), SPS ( $\sim 20 \text{ GeV}$ ), and RHIC ( $130 \text{ GeV}$ )

The study for RHIC data

*P. Braun-Munzinger, D. Magestro, K. Redlich, and J. Stachel, hep-ph/0105229*

*W. Florkowski, W. Broniowski, and M. Michalec, nucl-th/0106009*

*F. Becattini, workshop in Trento, June, 2001.*

*N. Xu and M. Kaneta, nucl-exp/0104021*

# Model

Hadron resonance ideal gas

Refs. J.Rafelski PLB(1991)333  
J.Sollfrank et al. PRC59(1999)1637

Particle density  
of each particle     $\rho_i = \gamma_s^{|s_i|} \frac{g_i}{2\pi^2} T_{ch}^3 \left(\frac{m_i}{T_{ch}}\right)^2 K_2(m_i/T_{ch}) \lambda_q^{Q_i} \lambda_s^{s_i}$

$$\lambda_q = \exp(\mu_q/T_{ch}), \quad \lambda_s = \exp(\mu_s/T_{ch})$$

$Q_i$  : 1 for u and d, -1 for  $\bar{u}$  and  $\bar{d}$

$s_i$  : 1 for s, -1 for  $\bar{s}$

$g_i$  : spin-isospin freedom

$m_i$  : particle mass

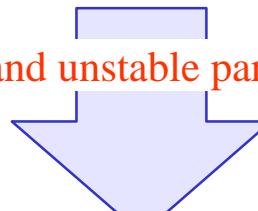
$T_{ch}$  : Chemical freeze-out temperature

$\mu_q$  : light-quark chemical potential

$\mu_s$  : strangeness chemical potential

$\gamma_s$  : strangeness saturation factor

All resonances and unstable particles are decayed



*Comparable particle ratios to experimental data*

# Model (cont.)

- Hadron resonance ideal gas
  - including higher mass resonances ( $\leq 1.7\text{GeV}$ )

$\pi, \eta, \rho, \omega, \eta', \phi, f_0(980), a_0(980), h_1(1170), b_1(1235), a_1(1260), f_2(1270), f_1(1285), \eta(1295), \pi(1300), a_2(1320), f_0(1370), \eta(1440), \omega(1420), f_1(1420), \rho(1450), f_0(1500), f_1(1510), f_2'(1525), \omega(1600), \pi_2(1670), \phi(1680), \rho(1690), f_j(1710), \rho(1700)$

$p, n, N(1440), N(1520), N(1535), N(1650), N(1675), N(1680), N(1700)$

$\Delta(1232), \Delta(1600), \Delta(1620), \Delta(1700)$

$K, K^*, K_1(1270), K_1(1400), K^*(1410), K_0^*(1430), K_2^*(1430), K^*(1680)$

$\Lambda, \Lambda(1450), \Lambda(1520), \Lambda(1600), \Lambda(1670), \Lambda(1690)$

$\Sigma, \Sigma(1385), \Sigma(1660), \Sigma(1670)$

$\Xi, \Xi(1530), \Xi(1690)$

$\Omega$

- For mid-rapidity, no requirement of
  - Strangeness neutrality
  - Charge/Isospin conservation



# Ratio data

STAR, PHENIX, BRAHMS, PHOBOS, NA49, NA61, LHCb, CMS, ATLAS, ALICE, STAR, PHENIX, BRAHMS, PHOBOS, NA49, NA61, LHCb, CMS, ATLAS, ALICE

Central				Peripheral			
$K^+/K^-$	$1.13 \pm 0.01 \pm 0.06$	(STAR)		$K^+/K^-$	$1.11 \pm 0.02 \pm 0.06$	(STAR)	
	$1.29 \pm 0.07 \pm 0.19$	(PHENIX)			$1.52 \pm 0.16 \pm 0.22$	(PHENIX)	
	$1.10 \pm 0.08 \pm 0.07$	(PHOBOS)					
	$1.12 \pm 0.07 \pm 0.06$	(BRAHMS)					
$\bar{p}/p$	$0.61 \pm 0.02 \pm 0.06$	(STAR)	$\bar{p}/p$	$0.68 \pm 0.03 \pm 0.07$	(STAR)		
	$0.61 \pm 0.02 \pm 0.07$	(PHENIX)		$0.63 \pm 0.03 \pm 0.07$	(PHENIX)		
	$0.60 \pm 0.04 \pm 0.06$	(PHOBOS)					
	$0.64 \pm 0.04 \pm 0.06$	(BRAHMS)					
$\bar{\Lambda}/\Lambda$	$0.70 \pm 0.03$	(STAR)	$\bar{\Lambda}/\Lambda$	$0.88 \pm 0.06$			
$\bar{\Xi}^+/\Xi^-$	$0.82 \pm 0.08$	(STAR)					
$\pi^-/\pi^+$	$0.95 \pm 0.03 \pm 0.05$	(BRAHMS)					
	$1.00 \pm 0.01 \pm 0.02$	(PHOBOS)					
$\bar{p}/\pi^-$	$0.080 \pm 0.005$	(STAR)	$\bar{p}/\pi^-$	$0.050 \pm 0.002$			
$K^-/\pi^-$	$0.150 \pm 0.004$	(STAR)	$K^-/\pi^-$	$0.101 \pm 0.003$			
$K^{*0}/h^-$	$0.060 \pm 0.007 \pm 0.015$	(STAR)	$\frac{(K^{*0} + \bar{K}^{*0})/2}{h^-}$	$0.058 \pm 0.010 \pm 0.015$	(STAR)		
	$0.058 \pm 0.006 \pm 0.015$	(STAR)					

Red : the values from slide of QM2001

Blue: the values from figure in proceedings of QM2001

Black : PRL (including submitted)

Masashi Kaneta, LBNL



# Freeze-out parameters

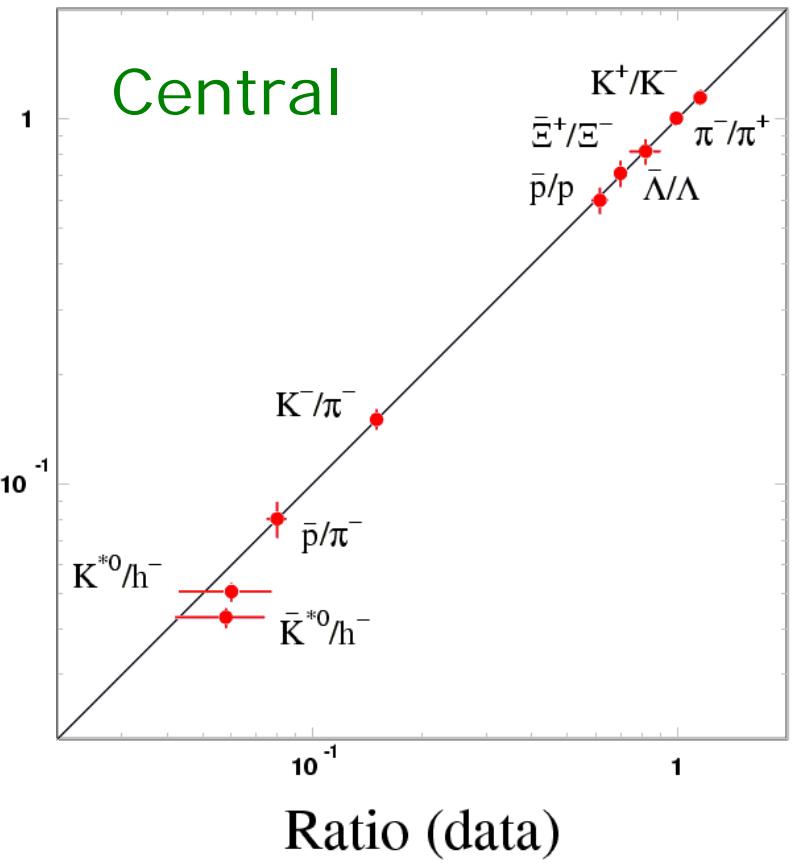
	Central	Peripheral
$T_{ch}$ [MeV]	$186 \pm 8$	$147 \pm 2$
$\mu_q$ [MeV]	$16.7 \pm 1.7$	$8.8 \pm 1.6$
$\mu_s$ [MeV]	$1.2 \pm 2.4$	$-2.9 \pm 3.0$
$\gamma_s$	$0.92 \pm 0.04$	$0.60 \pm 0.02$
$\chi^2/dof$	$1.9 / 5$	$4.8 / 2$
$e$ [MeV/fm <sup>3</sup> ]	$1160 \pm^{450}_{340}$	$171 \pm^{21}_{19}$
$r$ [1/fm <sup>3</sup> ]	$0.99 \pm^{0.32}_{0.25}$	$0.21 \pm 0.02$
$P$ [MeV/fm <sup>3</sup> ]	$184 \pm^{69}_{52}$	$31 \pm 3$

Note: The errors are estimated as  $\chi^2_{min} + 1$   
The feed-down factor of 0.5 is assumed.

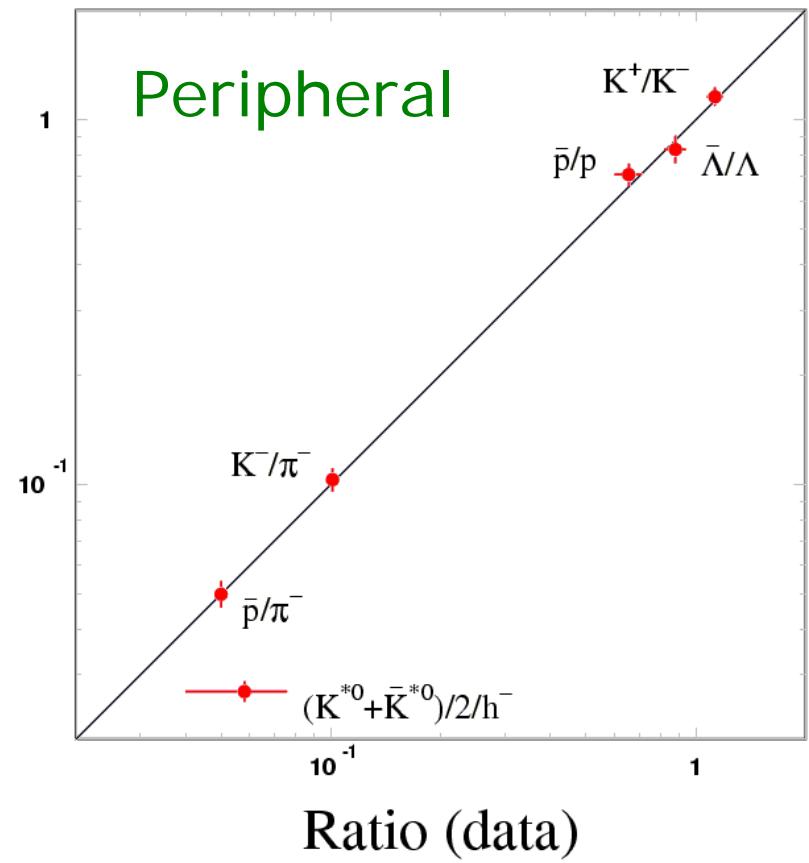
# Ratios, experiment vs. model

•  $\bar{p}/p$ ,  $K^+/\bar{K}^0$ ,  $\bar{\Lambda}/\Lambda$ ,  $\bar{\Xi}^0/\Xi^-$ ,  $\bar{p}/\pi^-$ ,  $K^+/\pi^-$ ,  $\bar{K}^{*0}/h^-$ ,  $(K^{*0}+\bar{K}^{*0})/2/h^-$ ,  $\bar{p}/\pi^+$ ,  $\Lambda/\bar{\Lambda}$ ,  $\pi^-/\pi^+$

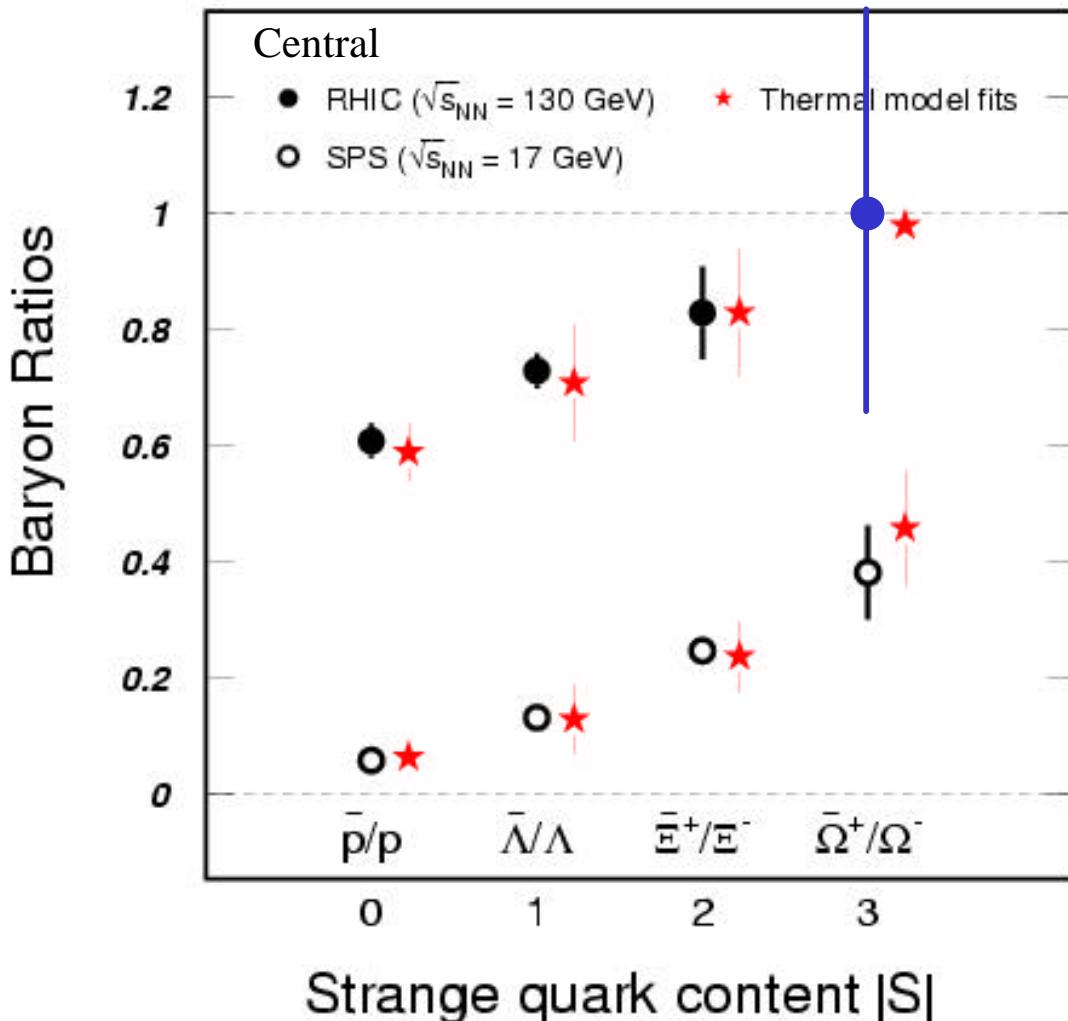
Ratio (thermal fit)



Ratio (thermal fit)



# Strange baryon ratios



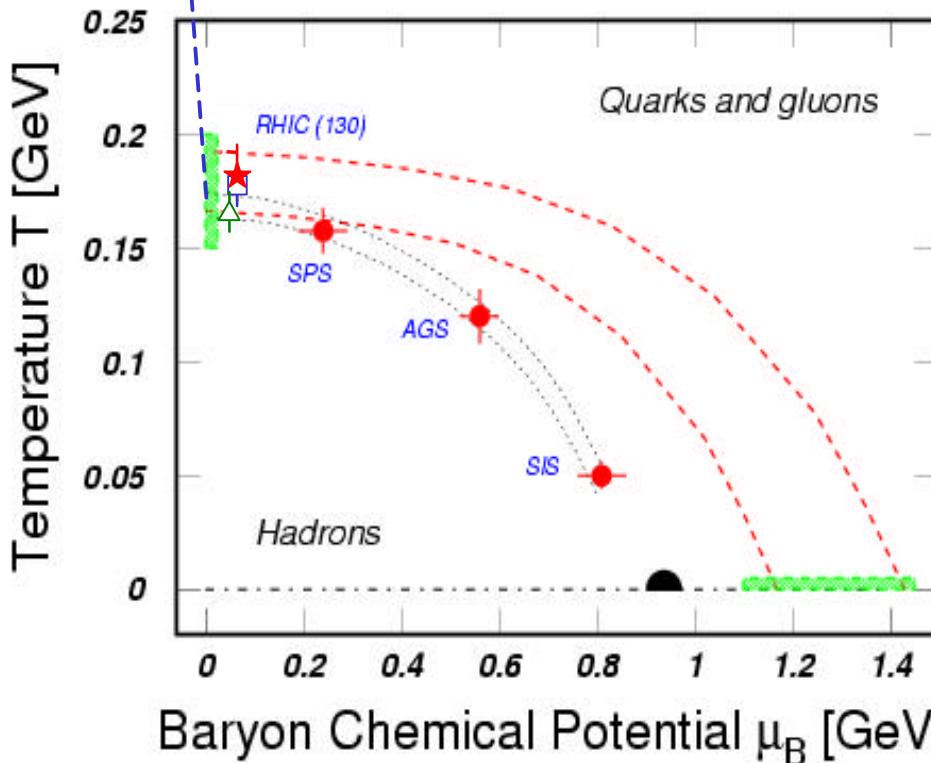
see also J. Zimanyi *et al*,  
hep-ph/0103156  
(quark coalescence)



# Systematics

Lattice QCD  
predictions

## Central collisions



- ★ This analysis
- P.Braun-Munzinger et al.
- △ W. Florkowski et al.

Temperature increases with beam energy and being close to phase boundary

Neutron star

— parton-hadron phase boundary

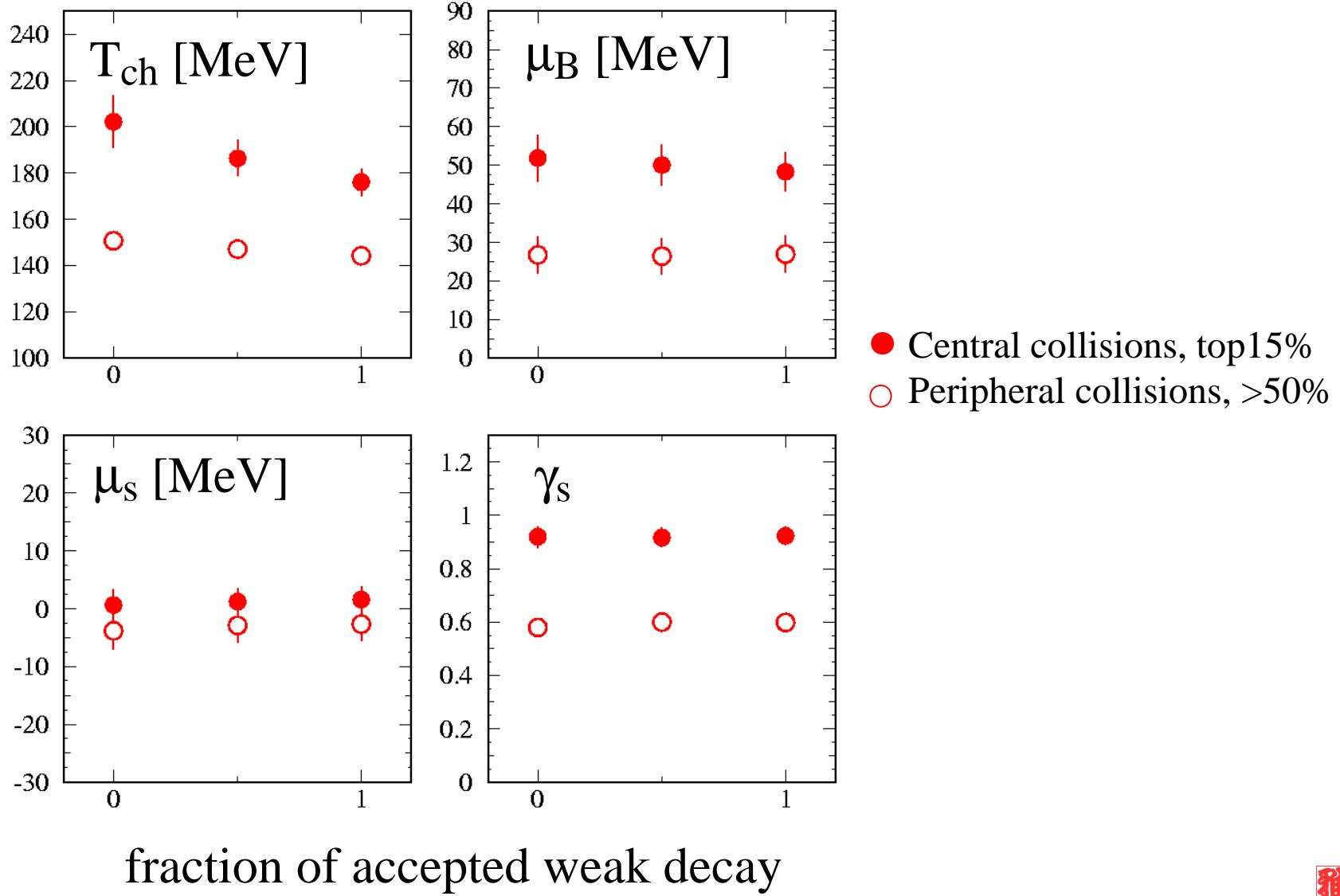
······ ··· ··· ··· <E>/<N>~1GeV, J.Cleymans and K.Redlich, PRC60 (1999) 054908



# Model uncertainties

- Mass cut-off
- Boltzmann vs. Boson/Fermion
- Weak decay feed-down
  - Depend on particle species (i.e.  $c_t$ )
  - No equal opportunity to decayed particles
    - deferent  $p_T$  kick
  - Depend on detector
- **Test of the effect in case of**
  - fraction of accepted weak decay ( $f_W$ ) = 0, 0.5, 1.0

# Feed-down effects



# Summary

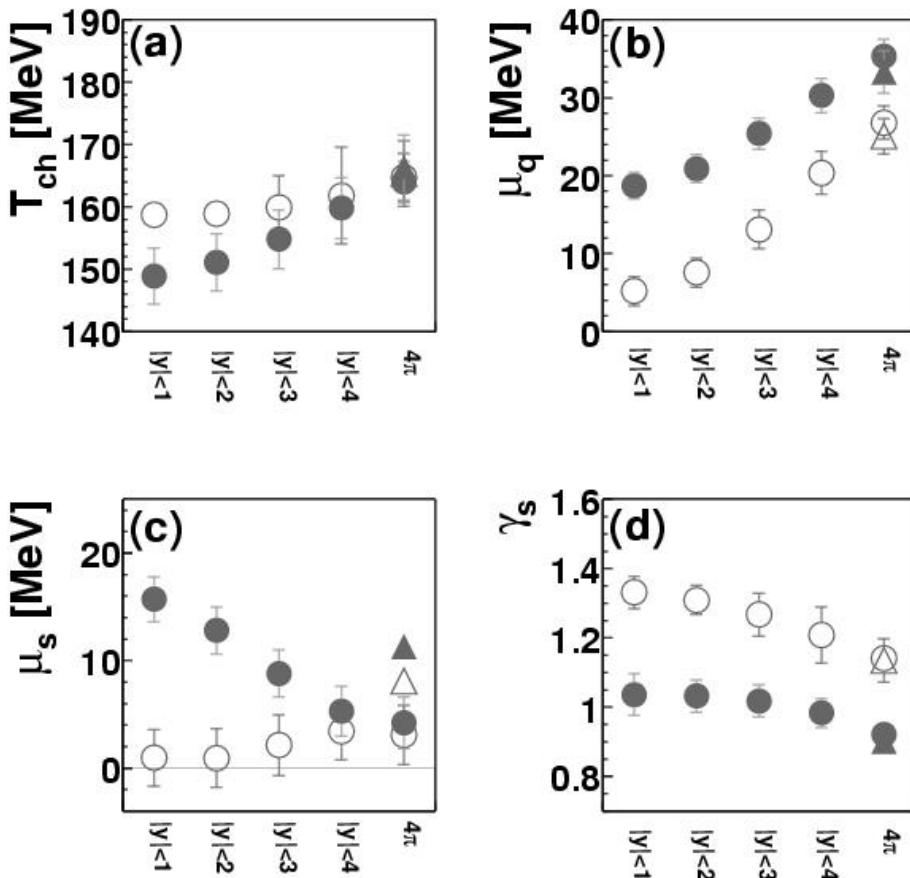
- Only mid-rapidity ratios used;
- With selected  $f_w$  the  $T_{ch}$  and  $\mu$  are consistent with what expected;
- Centrality dependence;
- Systematic uncertainty needed to be evaluated;

# Open issues

- Particle ratios are described by statistical model well
  - Dynamical information?
- Global vs. local equilibration
- Connection between  $T_{ch}$  and Lattice QCD  $T_c$ ?

# Test: rapidity dependence

*Au + Au at 200 GeV ( $b \leq 3$  fm)*

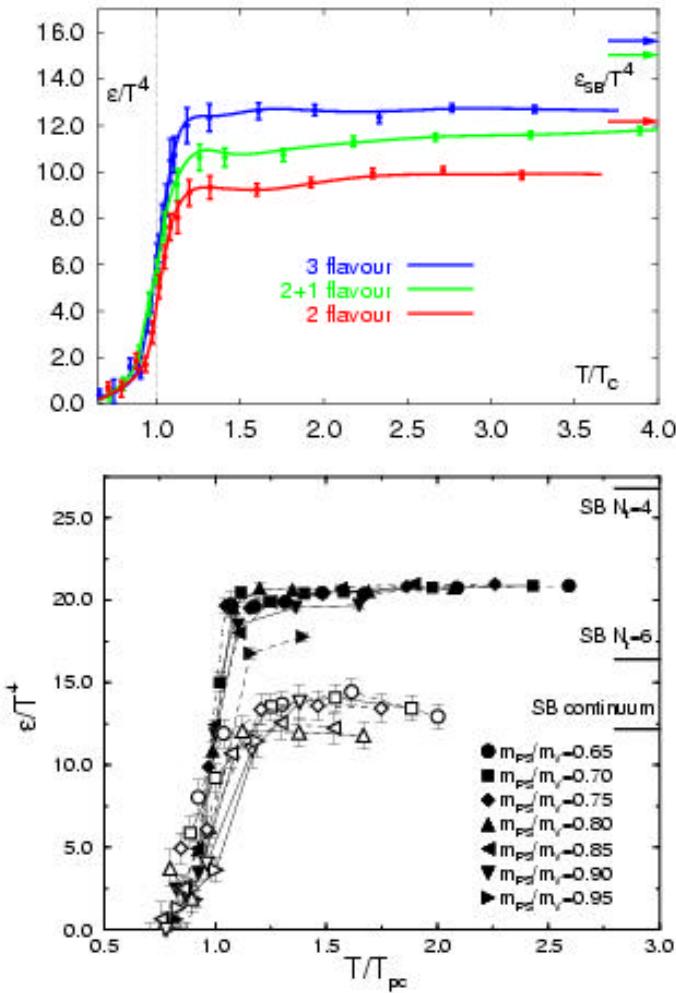


- RQMD(v2.4)
- NEXUS(V1.1)

- (a) Temperature: Increasing as the rapidity width  $\Delta y$  open up;
- (b) Baryon chemical potential: increase with  $\Delta y$ ;
- (c) Strange chemical potential: decrease with  $\Delta y$ ;
- (d) Strange saturation factor: decrease with  $\Delta y$ ;

**Thermal parameters depend on the kinetic cuts!**

# Open issues



F. Karsch, hep-lat/0106019

- 1) Not fully ideal system at  $4T_c$
- 2) Collective effects ?
- 3) ???

# Freeze-out parameters

重离子碰撞の熱力学的・統計的モデルによる結果  
と実験との比較

	Central			Peripheral		
$T_{ch}$ [MeV]	<b><math>202 \pm 11</math></b>	<b><math>186 \pm 8</math></b>	<b><math>176 \pm 6.0</math></b>	<b><math>151 \pm 2</math></b>	<b><math>147 \pm 2</math></b>	<b><math>144 \pm 2</math></b>
$\mu_q$ [MeV]	<b><math>17.3 \pm 2.0</math></b>	<b><math>16.7 \pm 1.7</math></b>	<b><math>16.1 \pm 1.8</math></b>	<b><math>8.9 \pm 1.7</math></b>	<b><math>8.8 \pm 1.6</math></b>	<b><math>9.0 \pm 1.6</math></b>
$\mu_s$ [MeV]	<b><math>0.6 \pm 2.8</math></b>	<b><math>1.2 \pm 2.4</math></b>	<b><math>1.6 \pm 2.2</math></b>	<b><math>-3.8 \pm 3.2</math></b>	<b><math>-2.9 \pm 3.0</math></b>	<b><math>-2.7 \pm 2.9</math></b>
$\gamma_s$	<b><math>0.92 \pm 0.04</math></b>	<b><math>0.92 \pm 0.04</math></b>	<b><math>0.92 \pm 0.04</math></b>	<b><math>0.58 \pm 0.02</math></b>	<b><math>0.60 \pm 0.02</math></b>	<b><math>0.60 \pm 0.02</math></b>
$\chi^2/\text{dof}$	<b><math>1.29/5</math></b>	<b><math>1.90/5</math></b>	<b><math>2.71/5</math></b>	<b><math>4.63/2</math></b>	<b><math>4.80/2</math></b>	<b><math>4.97/2</math></b>
$e$ [MeV/fm <sup>3</sup> ]	2140+1136-780	1160+450-340	758+235-184	202+26-23	171+21-19	149+17-16
$r$ [1/fm <sup>3</sup> ]	1.66+0.74-0.53	0.99+0.32-0.25	0.69+0.18-0.14	0.24+0.02	0.21+0.02	0.19+0.01
$P$ [MeV/fm <sup>3</sup> ]	335+177-121	184+70-52	122+36-28	36.0+4.2-2.8	30.9+3.4-3.0	27.3+2.8-2.6
$e/T_{ch}^4$	9.8+2.2-2.0	<b><math>7.4 \pm 1.3 - 1.2</math></b>	6.1+0.9-0.8	3.0+0.2-0.2	<b><math>2.8 \pm 0.2 - 0.2</math></b>	2.6+0.2-0.2